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Taking Control of Dead Zone of Radiolocation Station by the Automatic Acting Electro-Optic System

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ABSTRACT

In the article, in order to effectively detect unmanned aerial vehicles and create an effective radar location, a mathematical model of covering the dead zone of radiolocation stations with an electro-optical system installed on an automatically operating bench placed on a visual observation post, opened in the direction of the likely flight of the enemy, was built and a comparison was made on concrete examples. The aim of the research work is to build a mathematical model of the monitoring of the dead zone of the radiolocation station with the help of an electro-optical system mounted on an automatically operating bench placed on a visual observation post. The following problems are solved in the article: analysis of the characteristics of the radiolocation area; development of a mathematical model for evaluating the dead zone of radiolocation stations with an automatically operating electro-optical system mounted on a bench; assessment of the probability of the unmanned aerial vehicle passing through the field of view of the electro-optical system without detection. The following research methods are used to solve problems: synthesis, theoretical analysis, mathematical modeling, comparative analysis. The following results were obtained: an electro-optical system automatically operating with a rotation period of T=10 [sec] mounted on a bench will detect the UAV traveling a distance of 27 km, for 138 times in 23 minutes , with a rotation period of T=20 [sec] mounted on a bench will detect the UAV covering a distance of 18 km, for 27 times in 9 minutes , with a rotation period of T=20 [sec] mounted on a bench will detect the UAV covering a distance of 3 km 3 times in 1 min. From the comparison of the obtained numbers and the reports made on the basis of the obtained mathematical algorithm, it can be concluded that it is possible to detect unmanned aerial vehicles by means of 1 automatically operating electro-optical system installed on the bench.

Keywords: Unmanned aerial vehicle; Dead zone; Radiolocation field; Automatically operating bench; Radiolocation station; Electro-optical system

1. INTRODUCTİON

Due to the increased demand for UAVs that have been successfully tested in modern local conflicts and wars, the Patriotic War, Local anti terrorist operations in 2023, and the ongoing Russia-Ukraine war, the world's well-known scientific institutions and companies in this field are constantly developing new types of UAVs are working towards the creation and improvement of UAVs. UAVs differ from each other in terms of purpose, size, function, flight distance, level of autonomy, design and a number of other features.

The development of UAVs for Air defense systems has become one of the main problems. Air defense systems cannot timely detect UAVs that are small in size, relatively silent and flying at low altitudes. At the same time, special colors and protective layers are used in the manufacture of UAVs, which makes it difficult to detect them with the eye or vision devices.

With the emergence of UAVs, the task of combating them has become significantly more relevant. After detecting and identifying UAVs by radar stations, it is necessary to take measures for its neutralisation.

The conducted analyzes show that the use of air defense and radioelectronic warfare systems is considered effective for the application of all types of UAVs. Countermeasures against unmanned aerial vehicle based on the joint use of radioelectronic warfare and air defense systems are already actively used in the practice of local combat operations, as well as for the protection of strategic objects[1-8]

An important aspect of effective countermeasures to UAVs by air defense units is their early detection. Early detection of a drone helps save time and make the right decision against it.

Based on the conducted analyzes and current armed conflicts, we can note that many methods are effectively used to detect UAVs. One of the most effective methods used is the detection of UAVs through RLSs[9].

Radar stations, other types of troop detection means, in interaction with visual observation posts are effectively used means to control the airspace. In local anti-terrorist measures that took place in 2023, RLSs were also effectively used to control the airspace. Based on the analysis of the Patriotic

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War in 2020, Local anti-terrorist measures in 2023, and many armed conflicts, it remains a problem to effectively detect and identify UAVs through RLSs, especially UAVs with a small effective reflection area[10].

The large number of applications of UAVs by the enemy requires the establishment of an anti-UAV system in every aviation and air defense unit of the Air Force. The issue of detecting and countering UAVs should be taken into account when building the system. In order to more effectively combat UAVs within the system, their rapid long-range detection as well as dead-cannon detection is an important factor[11].

A dead gap is a part of space above the head of a radar station that cannot be seen by RLS (Fig. 1). The presence of the part located above the head of the radar station is conditioned by the appropriate selection of the orientation diagram in the vertical plane, which depends on the relief of the area in the zone of influence of the station, the nature of the position, the height of the antenna and the technical parameters of the RLS. It is impossible to detect and track air targets in the space above the head of the radar station[12].

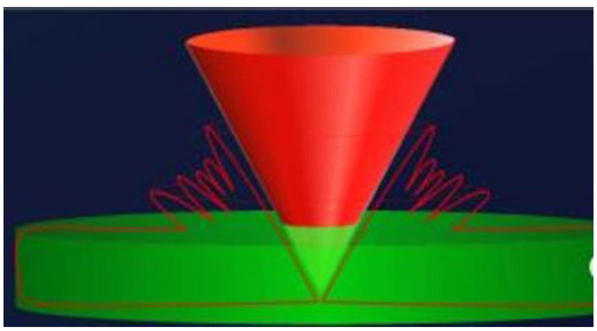

Figure 1. Dead zone (Zone on RLS).

1.1 Analysis of the Latest Studies and Publications

A literature review and analysis of other authors' articles and studies help provide more information and context on the issue. Below are examples of literature review results. Feasibility analysis of long-range detection of unmanned aerial vehicles using robotic telescopes was investigated[13]. In[14], the results obtained in the field tests of detection and tracking of UAVs operating at low altitude with a small effective reflection area and simultaneous detection of several UAVs using a sensor network were discussed, in[15] an efficient algorithm for detecting UAVs using cameras was presented. However, in none of these works, the issue of detection of UAVs in the dead zone was not investigated. In[16] the detection and tracking of small UAVs flying at low altitude, and at the same time the results obtained in the field tests of the detection of several UAVs using a sensor network consisting of acoustic antennas, small radar systems and optical sensors are discussed. In[17] is analyzed an autonomous drone detection and tracking system using a static wide-angle camera and a low-angle camera mounted on a rotating tower, proposed a combined multi-frame deep learning detection technique in which a frame from a zoomed-in tower camera is overlaid on a frame from a wide-angle static camera to make efficient use of memory and time. In[18], the problem of classification according to belonging to objects is solved by determining the spatial coordinates of the images of point objects found in the optical receiver system. An algebraic approach to solving this problem based on solving systems of linear equations with consideration of measurement noise is proposed.

The "Drone-Bird Detection Problem" was analysed to detect a drone appearing at a point in the video where birds may also be present[19]. A UAV detection framework based on video images was proposed. Depending on whether the video images are recorded by static cameras or moving cameras, it initially detects the regions containing the object by median background subtraction or deep learning-based object proposal method, respectively[20].

Problems encountered when using rapid test models are discussed in detail in the investigation of radars for air-fire control for operations[21].

The capabilities of special objects subjected to UAV attacks operating in a swarm are determined[22]. A countermeasure system against swarming UAVs is being discussed to protect specific objects from swarming UAV attacks. Currently used detection systems are analyzed and their application against swarming UAVs is revealed.

A sensor system is developed for high-energy lasers that will include detection using a single detector[23].

A literature review helps to understand the trends and progress for the detection of UAVs using an automatically acted bench-mounted electro-optical system. The use of samples helps to flesh out these approaches and technologies used by researchers to achieve the goal of detecting UAVs in a dead zone using mounted on an automatically operating bench electro-optical system.

The article considers the creation of an effective radiolocation area to increase the probability and effectiveness of the detection of UAVs. Thus, the detection of the UAV in the dead valley of the radar station through the electro-optical system installed on the automatically operating bench was considered and the evaluation results are being compared.

1.2 Purpose of the Research Work

To detect a UAV flying at a certain speed through how much electro-optical systems installed on an automatically operating bench, and is the calculation of the probability of passing without detection.

2. PERFORMİNG RESEARCH

2.1 Setting Issue of Evaluating the Invisible Zone Above the Head of the Radar Station by Means of Automatic Cameras Placed at the Visual Observation Post

Detection of UAVs and creation of an effective radar field, using an automatically operating camera placed on a visual observation post, control of the RLS dead gap can be organized in different ways. These methods differ from each other mainly depending on the rotation speed of the automatically operating camera placed on the visual observation post, the detection distance of the RLS, how the camera is directed and its viewing angle. It is clear that the implementation of an automatically operating camera placed in a visual observation post will reduce the dead gap of RLS.

The issue raised within the framework of this study is the development of a mathematical model of the detection of UAVs in a dead ravine depending on the number and speed of rotation of the camera.

2.2 Investigating of Problem Solving

The target detection distance of the RLS operating in the position d, and the characteristic angle of the dead zone (sector left out of observation) by α. It is clear that the radar station's unobserved zone can be described as a truncated cone, and the height of this cone is calculated by the Eqn.

$$h = dctg\frac{\alpha}{2} \tag{1}$$

It is assumed that near the radiolocation station (at a distance of $(10 \div 20[m])$ N number of electro-optical systems are placed on a rotary table to detect UAVs entering its unobserved sector (Fig. 2). Compared to the dimensions of the observation coverage of RLS, the distance between the camera placed on the visual surveillance post and the station operating in the position is very close, it can be considered with a fairly large accuracy that the point where the bench is located coincides with the point where the RLS is located. It is assumed that the bench rotates at a constant speed and its period of rotation T [m] is known.

It is also assumed that all electro-optical systems are of the same type and their viewing angle φ is known. Electro-optical systems are oriented so that their angle of view allows detection of UAVs that may enter the RLS's dead zone (to the unobserved zone).

A cross-section of an electro-optical system's viewing angle along the vertical plane can be described as the triangle OAB shown in Fig. 2. The passing of the UAV the distance AB at such plane can be considered as passing it from the control zone of the electro-optical system. Rotation of bench causes the formation of an annular viewing line around the RLS at the viewed altitude whose width is equal to $f \equiv |AB|$. If we consider the Eqn. (1), the distance f from the triangle OAB can be calculated as follows[24]:

$$|BC| = htg\left(\frac{\alpha}{2} - \varphi\right) \tag{2}$$

$$|AB| = d - |AB| = d - htg\left(\frac{\alpha}{2} - \varphi\right) = d - d\frac{\mathrm{tg}\left(\frac{\alpha}{2} - \varphi\right)}{\mathrm{tg}\frac{\alpha}{2}}, \tag{3}$$

$$f = d\left(1 - \frac{\mathrm{tg}\left(\frac{\alpha}{2} - \varphi\right)}{\mathrm{tg}\frac{\alpha}{2}}\right). \tag{4}$$

Let us estimate the probability that a UAV flying at a certain speed V will go undetected by the camera, depending on the number of cameras placed on the visual observation post.

It is clear that the time $\Delta t = f / V$ is required for the UAV flying at the speed V to cover the distance f müddəti tələb olunur and if the condition $\Delta t \geq T / N$ or

$$N\Delta t \geq T \tag{5}$$

is met, such UAV cannot cross the viewing line, avoiding the control of this or that electro-optical system. The Eqn. (5) allows to determining the maximum cycle time for the detection of UAVs moving at the considered speed by the N number electro-optical systems.

However, the speed of rotation of the used bench can increase due to various technical reasons. Suppose that inequality (5) is not satisfied, in other words,

$$N\Delta t < T \tag{6}$$

In this case, let's estimate the probability that the UAV will pass through the viewing zone of the electro-optical system without being detected.

Each electro-optical system rotates on the bench and reaches the location of the other electro-optical system relative to the Earth in T / N time. If condition (6) is satisfied, this period can be divided into 2 parts: $(0,\Delta t)$ and $(\Delta t, T/N)$. If we apply the geometric probability Eqn., the probability of the UAV passing through the viewing zone of the electro-optical system without detection is calculated as follows[25]:

$$P = \frac{\frac{T}{N} - \Delta t}{\frac{T}{N}}, \tag{7}$$

or

$$P = 1 - \frac{N\Delta t}{T}. \tag{8}$$

As can be seen from the Eqn. (8), as the cycle time of the bench increases, the probability of the UAV passing through the viewing area without being detected increases.

3. EVALUATİON OF LAYOUT SCHEMES (OPTIONS)

3.1 Option 1

Suppose that the characteristic invisible zone above the head of the station is α=120°, flight speed of dangerous UAV v=70[km/h], detection distance of a radiolocation station d=35[km]. One electro-optical system is installed on an automatically rotating bench located near the radiolocation station (Fig. 2). Let's accept that the rotation period of the bench is T=10[san], the distance seen by the camera L_v=40[km], angle of view is $\varphi = 40°$. In this case, to determine the number of automatically operating electro-optical systems installed on the bench, let's evaluate the considered variant (scheme) of the detection of the UAV in the dead zone:

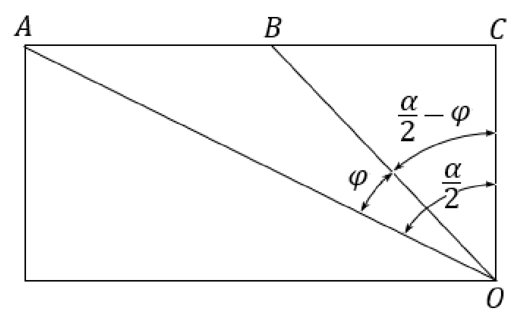

Figure 2. Calculation of the width of the annular control zone.

$$f = d\left(1 - \frac{\mathrm{tg}\left(\frac{\alpha}{2} - \varphi\right)}{\mathrm{tg}\frac{\alpha}{2}}\right); \tag{9}$$

$$f = 35\left(1 - \frac{\mathrm{tg}\left(\frac{120^\circ}{2} - 40^\circ\right)}{\mathrm{tg}\frac{120^\circ}{2}}\right) = 35\left(1 - \frac{\mathrm{tg}20^\circ}{\mathrm{tg}(60^\circ)}\right) = 27,64516\,km \tag{10}$$

$$\Delta t = f / V = \frac{27,64516}{70} \approx 23\mathrm{min} = 1380\,sec \tag{11}$$

$$N \geq \frac{T}{\Delta t}\frac{10\,sec}{1380\,sec} = 0,00725 \tag{12}$$

Since the condition N≥0,00725 is satisfied we can conclude that to detect the unmanned aerial vehicle flying at a speed of *v*=70[*km*/*h*] one electro-optical system should be installed on the rotary bench. Based on the obtained numbers, we can say that the UAV will cover the distance AB in 23 minutes. This means that the electro-optical system automatically operating with a rotation period of *T*=10[*sec*] mounted on the bench will detect the UAV 138 times in 23 min., covering a distance of 27,64516 km.

3.2 Option 2

Suppose that the characteristic invisible zone above the head of the station is α=120°, flight speed of dangerous UAV is *v*=120[*km*/*h*], detection distance of a radiolocation station is *d*=35[*km*]. One electro-optical system is installed on an automatically rotating bench located near the radiolocation station (Fig. 2). Let's accept that the rotation period of the bench is *T*=20[*sec*], the distance seen by the camera L_v=40[*km*], angle of view is $\varphi = 20°$. In this case, to determine the number of automatically operating electro-optical systems installed on the bench, let's evaluate the considered variant (scheme) of the detection of the UAV in the dead zone:

$$f = d\left(1 - \frac{\mathrm{tg}\left(\frac{\alpha}{2} - \varphi\right)}{\mathrm{tg}\frac{\alpha}{2}}\right); \tag{13}$$

$$f = \left(1 - \frac{\mathrm{tg}\left(\frac{120^\circ}{2} - 20^\circ\right)}{\mathrm{tg}\frac{120^\circ}{2}}\right) \tag{14}$$

$$f = 35\left(1 - \frac{\mathrm{tg}40^\circ}{\mathrm{tg}(60^\circ)}\right) \approx 18\,km; \tag{15}$$

$$\Delta t = f / V = \frac{18}{120} = \frac{18}{120} \approx 9 = 540\,sec \tag{16}$$

$$N \geq \frac{T}{\Delta t} = \frac{20\,sec}{540\,sec} = 0,03704; \tag{17}$$

Since the condition *N* ≥ 0,03704 is satisfied we can conclude that to detect the unmanned aerial vehicle flying at a speed of *v*=120[*km*/*h*] one electro-optical system should be installed on the rotary bench. Based on the obtained numbers, we can say that the UAV will cover the distance AB in 9 min. This means that the electro-optical system automatically operating with a rotation period of *T*=20[*sec*] mounted on the bench will detect the UAV 27 times in 9 min., covering a distance of 18 km.

3.3 Option 3

Suppose that the characteristic invisible zone above the head of the station is α=120°, flight speed of dangerous UAV is *v*=150[*km*/*h*], detection distance of a radiolocation station is *d*=10[*km*]. One electro-optical system is installed on an automatically rotating bench located near the radiolocation station (Fig. 2). Let's accept that the rotation period of the bench is *T*=20[*sec*], the distance seen by the camera L_v=40[*km*], angle of view is $\varphi = 10°$. In this case, to determine the number of automatically operating electro-optical systems installed on the bench, let's evaluate the considered variant (scheme) of the detection of the UAV in the dead zone:

$$f = d\left(1 - \frac{\mathrm{tg}\left(\frac{\alpha}{2} - \varphi\right)}{\mathrm{tg}\frac{\alpha}{2}}\right); \tag{18}$$

$$f = 10\left(1 - \frac{\mathrm{tg}\left(\frac{120^\circ}{2} - 20^\circ\right)}{\mathrm{tg}\frac{120^\circ}{2}}\right) = 10\left(1 - \frac{\mathrm{tg}50^\circ}{\mathrm{tg}(60^\circ)}\right) \approx 3\,km; \tag{19}$$

$$\Delta t = f / V = \frac{3}{150} \approx 1\mathrm{min} = 60\ \mathrm{sec}; \tag{20}$$

$$N \geq \frac{T}{\Delta t} = \frac{20}{60} = 0,33\,sec. \tag{21}$$

Since the condition $N \geq 0,33$ is satisfied we can conclude that to detect the unmanned aerial vehicle flying at a speed of *v*=150[*km*/*h*] one electro-optical system should be installed on the rotary bench. Based on the obtained numbers, we can say that the UAV will cover the distance AB in 1 min. This means that the electro-optical system automatically operating with a rotation period of *T*=20[*sec*] mounted on the bench will detect the UAV 3 times in 1 min, covering a distance of 3 km.

4. CONCLUSİON

In this work, the issue of keeping the invisible zone on the head of the RLS under control by means of cameras placed on the visual surveillance post was investigated. Taking into account the angle of view of the camera, the distance it can see, the invisible zone above the head of the RLS, the height at which the drone can enter the invisible zone above the head of the RLS, the number of cameras placed on the visual reconnaissance post and the distance between the stations, according to the reports made, the invisible zone above the head of the station it is possible to detect UAVs in the zone through cameras placed at the visual observation post.

As a result, we can note that according to the reports made on the basis of the obtained mathematical algorithm, it is possible to detect unmanned aerial vehicles by means of 1 automatically operating electro-optical system installed on the bench.

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In the current study, the author was involved in the preparation of the introduction, conducting research and reports, and reviewing the literature.